FORESTRY

FRDA REPORT 128

DEVELOPMENT OF LIVE LIMBS ON STUMPS FOLLOWING JUVENILE SPACING

by
Patrick D. Forrester
Marc A. von der Gönna

FOREST RESOURCE DEVELOPMENT AGREEMENT

Canada

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as Special Report SR-69

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July 1990

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ISSN 0835-0752
ISBN 0-662-18159-X
Fo29-19/128E

91-01516/

Canadian Cataloguing in Publication Data

Forrester, Patrick
Development of live limbs on stumps following juvenile spacing.
(FRDA report, ISSN 0835-0752; 128)

On cover: Canada/BC Forest Resource Development Agreement
Also issued by Forest Engineering Research Institute of Canada as Special report SR-69.

Includes bibliographical references.
ISBN 0-662-18159-X

1. Lodgepole pine - British Columbia - Spacing. 2. Western Hemlock - British Columbia - Spacing. 3. Lodgepole pine - British Columbia - Growth. 4. Western hemlock - British Columbia - Growth. I. Von der Gönna, Marc A. (Marc Andrew), 1962 - . II. Canada. Forestry Canada. III. Canada - British Columbia Forest Resource Development Agreement. IV. Title. V. Series.

SD397.C7F67 1990 634.9'751 C90-092262-1

Abstract

In 1987 and 1988, spacing (precommercial thinning) was undertaken on three one-hectare blocks of Interior B.C. lodgepole pine and two one-hectare blocks of Coastal western hemlock. Each block received four different treatments during spacing. The survival and development of live limbs on cut stumps are documented. Pre- and post-spacing stand densities, clearing-saw productivity and costs are also reported. This project was funded by the Canada/British Columbia Forest Resources Development Agreement (FRDA) under agreement No. F-52-43-102 and the Forest Engineering Research Institute of Canada (FERIC).

Acknowledgements

The authors are grateful for the cooperation and assistance provided by Paul White, B.C. Ministry of Forests, Cranbrook; Bill Aspinall, Weyerhaeuser Canada Limited, Princeton; Lou Tromp, B.C. Ministry of Forests, Williams Lake; Jim Loftus, MacMillan Bloedel Limited, Eve River; and Dave Bain, Fletcher Challenge Canada Limited, Kokish. Thanks also to Craig Dorion, Sylvi Holmsen, Neil Marshall, Rick Kooistra, and Kelly Hutchinson of FERIC for their assistance in the field; Clarence Simons of Forestry Canada, Victoria for assisting with the initial study design; Dr. Tony Kozak of the University of British Columbia (Faculty of Forestry) for helping with the statistical analysis; and Kathi Patton, Kathy Prochnau, Jennifer Tan, and Jean Sorensen for their assistance in report preparation.

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Summary

During 1987 and 1988 the Forest Engineering Research Institute of Canada (FERIC) undertook juvenile spacing (precommercial thinning) in three stands of British Columbia Interior lodgepole pine and two stands of Coastal western hemlock. The objective was to document the survival and development of live limbs on cut stumps. The potential for competing trees to develop from these remaining limbs is of concern to Coastal and Interior foresters when spacing stands 10 to 20 years of age. Follow-up visits to each site were made by FERIC staff in the autumns of 1988 and 1989 to monitor the survival and growth of the live limbs remaining on the stumps. Project set-up and site-location assistance was provided by Forestry Canada, the British Columbia Ministry of Forests, MacMillan Bloedel Limited, Weyerhaeuser Canada Limited, and Fletcher Challenge Canada Limited.

Experimental blocks, one hectare in size, were laid out in the vicinities of Cranbrook, Princeton, Riske Creek, Eve River, and Beaver Cove. After site selection, each block was divided into four 0.25-ha treatment blocks, and each treatment block was randomly assigned one of the following treatments:

- Low trim—cutting stems as low as possible and trying to remove all remaining live limbs.
- Low leave—cutting stems as low as possible but leaving all remaining limbs.
- High trim—cutting stems at a height of 30 cm and trying to remove all remaining live limbs.
- High leave—cutting stems at a height of 30 cm but leaving all remaining live limbs.

A manual clearing saw was used to do the trimming, concurrently with the spacing treatment.

Detailed timing information was collected during each treatment. The results of this time and productivity study are detailed in the FERIC report, *The Effect of Live-Limb Removal on Clearing-Saw Productivity*, Technical Note TN-129. The cutting time per hectare was generally related to stand density and difficulty of treatment. Productivity on the Interior lodgepole pine sites ranged from 10.0 to 35.5 h/ha for trim treatments, and from 5.4 to 28.1 h/ha for leave treatments. Productivity on the Coastal western hemlock sites ranged from 38.4 to 52.1 h/ha and 33.8 to 45.5 h/ha, for the trim and leave treatments respectively. Treatment costs ranged from $125/ha to $830/ha for the Interior pine sites and from $785/ha to $1215/ha for the Coastal hemlock sites. Generally the leave treatments had lower costs.

When spacing was completed, stumps with live limbs were randomly selected, and a maximum of 50 per treatment per site were tagged. Measurements of stump diameter and height, live-limb diameter and height, live-limb green length and total length, distance to and type of nearest competition, and distance to the nearest crop tree were recorded. Tagged stumps were remeasured after one and two growing seasons.

The trim treatments left approximately 50% fewer stumps with live limbs than the leave treatments. Mortality of tagged stumps occurred throughout the first two growing seasons. Survival to 1989 ranged from 6 to 81% for the Interior pine and from 43 to 80% for the Coastal hemlock. Survival was lowest in the low-trim treatment and highest in the high-leave treatment for both pine and hemlock. Analysis of variance (ANOVA) testing of 1988 and 1989 survival data showed both trim versus leave and low-cut versus high-cut treatments significantly lowered survival of tagged stumps. Further analysis revealed that stumps with initially smaller diameters, greater heights, and more live limbs per stump had significantly higher survival than stumps with greater diameters, lower heights, and fewer live limbs.

Limb-growth characteristics of surviving stumps indicated that the branches were healthy and would continue to grow at least until crown closure by the crop trees. In the Interior pine, ANOVA testing showed that branch diameter, total length, green length, and number of branches per stump were significantly lower for the trim treatments than for the leave treatments. This suggests that stumps in the leave treatments are more vigorous than stumps in the trim treatments. In contrast, the number of branches per stump was significantly different when the high-cut treatment was compared to the low-cut treatment. In the Coastal hemlock, branch growth and development were similar for all treatments on both sites. ANOVA testing showed that treatments had no significant effect on any of the measured characteristics. This may be a result of the characteristic shade tolerance of this species.

Of the two main treatments, the trim versus leave treatment had the greatest effect on stump survival. Of the four treatment combinations, high leave had the greatest survival, whereas the other three treatment combinations had lower survival rates which were not significantly different from each other. Though extra effort is required and costs are higher for the trim treatment, these need only be expended if cutting low is not a feasible treatment option; otherwise, low leave may be the most cost effective and operationally acceptable treatment method.

This project was jointly funded by the Canada/British Columbia Forest Resources Development Agreement (FRDA) through the Pacific Forestry Centre of Forestry Canada, and FERIC.

INTRODUCTION

During 1987 and 1988 the Forest Engineering Research Institute of Canada (FERIC) undertook juvenile spacing (precommercial thinning) in three stands of British Columbia Interior lodgepole pine (*Pinus contorta* var. *latifolia* Englem.) and two stands of Coastal western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) (Hosie 1979). The objective was to document the survival and development of live limbs remaining on stumps, and to see if survival and development are affected by cutting stumps high or low and/or by trimming or not trimming the live limbs. The potential for competing trees to develop from these remaining live limbs is of concern to Coastal and Interior foresters when spacing stands 10 to 20 years of age. Although this study was carried out using manual clearing saws, the results are also important when determining parameters for mechanical strip thinners. Follow-up visits to each site were made by FERIC staff in the autumns of 1988 and 1989 to monitor the survival and growth of the live limbs remaining on the stumps. Project set-up and site-location assistance was provided by Forestry Canada, the British Columbia Ministry of Forests, MacMillan Bloedel Limited, Weyerhaeuser Canada Limited, and Fletcher Challenge Canada Limited.

This report presents the data collected on the survival and growth of limbs on stumps during the two-year study period, after juvenile spacing was undertaken with clearing saws. FERIC Technical Note TN-129, titled *The Effects of Live-Limb Removal on Clearing Saw Productivity* is the source for the background information contained in this report. Productivity results are also included here for comparison with the stump-survival and limb-growth data.

This project was jointly funded by the Canada/British Columbia Forest Resources Development Agreement (FRDA) through the Pacific Forestry Centre of Forestry Canada, and FERIC.

STUDY METHODS

Experimental blocks, one hectare in size, were laid out in the vicinities of Cranbrook, Princeton, Riske Creek, Eve River, and Beaver Cove (Figure 1). Study sites were chosen based upon the frequency of live limbs at and below 10 cm, and the homogeneity of the stand. Ten centimetres was considered the closest point to the ground at which the clearing saw could work with maximum productivity. Working at this height ensured the saw required a minimum of sharpening.

After site selection, each block was divided into four 0.25-ha treatment blocks (50 m x 50 m), with boundaries perpendicular to the slope. Each treatment block was randomly assigned one of the following treatments:

- Low trim—cutting stems as low as possible and trying to remove all remaining live limbs.
- Low leave—cutting stems as low as possible but leaving all remaining limbs.

Figure 1. Location of study sites.

- High trim—cutting stems at a height of 30 cm and trying to remove all remaining live limbs.
- High leave—cutting stems at 30 cm but leaving all remaining limbs.

For the sake of brevity, these treatments will be called low trim, low leave, high trim, and high leave throughout the report. Note that the experimental design is a two-by-two factorial, with "high cut versus low cut" and "trim versus leave" as the main treatments tested. The "trim" treatments were introduced to quantify the effort required to reduce the potential competition to crop trees from surviving live limbs on the stumps. A manual clearing saw was used to do the trimming, concurrently with the spacing treatment.

Within each treatment block, randomly selected 1/500-ha (20 m^2) plots, on a predetermined grid, were established. In each plot, stand density and species composition were recorded for the whole plot. One-quarter of each plot was randomly selected for intensive measurement. Here, tree species, stem diameter at ground height, height to the lowest live limb, and total tree height were recorded; as well, plot aspect, average slope over 25 m, and visual slash assessment were noted.

After the stand information was collected for each of the four treatment blocks, treatments were randomly assigned and thinning began. Detailed timing information was collected during each treatment. The results of this time and productivity study are detailed in the FERIC report, *The Effects of Live-limb Removal on Clearing-Saw Productivity*, Technical Note TN-129.

When the spacing was completed, 10 randomly selected 1/500 ha (20 m^2) plots were permanently established in each treatment block. Within these plots, the number of stumps with and without low live limbs were tallied and recorded. In each plot, five randomly chosen stumps with live limbs were tagged, to a maximum of 50 per treatment for the 10 plots. If five stumps with live limbs were not available in a given plot, more than

five were chosen at the next plot to make up the difference. The following measurements were made:

- stump diameter and height
- live-limb diameter and height
- live-limb green length and total length
- distance to and type of nearest competition
- distance to the nearest crop tree.

The categories of competition were: stump with live limbs, brush, sapling, and crop tree. Tagged stumps were remeasured after one growing season and again after a second growing season. In addition, incidence of epicormic branching was noted. Stumps with no live limbs or epicormic shoots were considered dead.

Analysis of variance (ANOVA) testing was carried out on 1988 and 1989 survival data, and on the average characteristics of 1989 survivors using SAS statistical package (SAS Institute Inc. 1985). Correlations between initial stump characteristics and subsequent survival rate were also tested.

The Sites

Three Interior lodgepole pine sites—Cranbrook, Princeton, and Riske Creek—and two Western hemlock sites on Vancouver Island—Beaver Cove and Eve River—were selected. Table 1 describes the selected stands.

The Stands

Interior. The Cranbrook and Princeton stands were composed predominantly of lodgepole pine (85% and 86%), with minor components of Interior Douglas-fir (*Pseudotsuga menziesii var. glauca* (Biessn.)), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and Engelmann spruce (*Picea engelmannii* Parry). Lodgepole pine comprised 99% of the Riske Creek stand. Table 2 shows stand densities and tree characteristics by treatment type. The Princeton stand was the least dense with an overall average of 11 450 stems/ha, while the Cranbrook stand was the most dense with 31 075 stems/ha. The stand density of the treatment blocks ranged from 9700 stems/ha at Princeton to 45 700 stems/ha at Cranbrook. All three sites exhibited clumpiness to some extent.

Overall, the tree diameter and height range over the three sites did not vary greatly. Average diameter at ground height ranged from 2.0 cm to 2.5 cm while average height ranged from 1.2 m to 1.6 m. However, on a treatment-block basis, the diameter ranged from 1.7 cm to 2.9 cm and height ranged from 1.0 m to 1.8 m.

Average heights of the lowest live limbs are shown in Table 2. Live-limb height should increase with density and age due to natural pruning; overall, the data support this trend. Cranbrook, with the highest stand density, has the highest mean height to the lowest live limb of 29.6 cm, followed by Riske Creek at 14.7 cm and Princeton at 10.8 cm. The distribution of live-limb branch heights, shown in Table 3, is of particular interest to this study because it will affect the results of the four treatments. The presence of live limbs on the trees at or below 30 cm ranged from an overall average of 62% in Cranbrook to 99% in Princeton.

Coastal. The two Coastal sites were dominated by western hemlock (97%), but included occasional Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), amabilis fir (*Abies amabilis* (Dougl.) Forbes), sitka spruce (*Picea sitchensis* (Bong.) Carr.), and western red cedar (*Thuja plicata* Donn). The Beaver Cove stand, over all four treatment blocks, averaged 36 275 stems/ha, compared to 45 225 stems/ha at Eve River (Table 2). The stand density, on a treatment-block basis, ranged from a low of 27 600 stems/ha in Beaver Cove to a high of 54 000 stems/ha in Eve River. The average diameter of all stems at Eve River was 1.6 cm, compared to 1.9 cm at Beaver Cove. Average heights were 1.6 m and 2.0 m respectively.

Table 1. Site Detail

Location	Ecological description [a]	Elevation (m)	Aspect	25-m slope (%)	Slash	Stand history	Stand age at time of treatment (yrs)
Interior							
Cranbrook	ESSFc	1 646	SE	28	Light-medium	Wild fire 1973 Salvage logged 1974	10-14
Princeton	MSb1	1 615	W	13	Light	Logged 1973 Drag scarified 1974	10-14
Riske Creek	SBSa	1 250	Flat	4	Light	Logged 1973	10-14
Coastal							
Eve River	CWHb1	200	NW	16	Light-medium	Logged 1977	8-10
Beaver Cove	CWHb1	320	SSW	18	Medium	Logged 1977-78	8-10

[a] From Klinka et al 1984, and Utzig et al 1983, and provided by company or BCMOF personnel.

Table 2. Diameter, Tree Height, Low Live Limb Height, and Density: Pretreatment Data

Location	Species	Treatment	Average stems/ha	Average stem diameter at ground level (cm)	Average height (m)	Height to first low live limb [a]		
						Average (cm)	Standard deviation	Range [b] (cm)
Interior								
Cranbrook	Lodgepole pine	Low trim	24 500	2.2	1.6	25.0	13.0	3-57
	(86%)	Low leave	24 500	2.5	1.8	29.4	18.2	5-130
		High trim	29 600	1.8	1.4	27.2	17.7	0-86
		High leave	45 700	2.1	1.6	36.6	19.6	4-107
	Overall average		31 075	2.1	1.6	29.6	18.5	0-130
Princeton	Lodgepole pine	Low trim	9 700	2.9	1.3	10.1	6.0	0-27
	(85%)	Low leave	11 100	2.8	1.3	9.1	6.8	1-34
		High trim	12 200	2.5	1.2	17.5	8.1	2-42
		High leave	12 800	2.2	1.0	11.3	7.9	1-49
	Overall average		11 450	2.5	1.2	10.8	7.5	0-49
Riske Creek	Lodgepole pine	Low trim	19 100	2.0	1.3	15.6	16.4	1-137
	(99%)	Low leave	16 200	2.0	1.2	10.2	8.4	1-50
		High trim	25 900	1.7	1.0	13.5	8.6	1-46
		High leave	16 800	2.5	1.5	19.5	17.2	1-121
	Overall average		19 500	2.0	1.2	14.7	13.1	1-137
Coastal								
Eve River	Hemlock	Low trim	51 400	2.1	2.0	43.0	34.7	1-134
	(97%)	Low leave	54 000	1.5	1.7	57.9	42.1	1-171
		High trim	42 000	1.6	1.5	26.6	31.7	1-136
		High leave	33 500	1.4	1.4	44.2	47.0	1-223
	Overall average		45 225	1.6	1.6	42.9	41.8	1-223
Beaver Cove	Hemlock	Low trim	44 400	2.0	2.2	55.0	53.0	1-190
	(97%)	Low leave	44 900	1.5	1.5	33.8	23.8	0-147
		High trim	28 200	2.4	2.2	25.9	27.4	2-127
		High leave	27 600	2.2	2.3	34.0	30.8	1-117
	Overall average		36 275	1.9	2.0	37.2	38.8	0-190

[a] Pine only for Cranbrook, Princeton, and Riske Creek. Hemlock only for Eve River and Beaver Cove.
[b] Live limbs originating at or below ground level were given a height of 0 cm.

Table 3. Height Distribution of Live Limbs: Pretreatment Data

Location	Treatment	≤10 cm (%)	>10 and ≤30 cm (%)	>30 cm (%)	Total (%)
Interior					
Cranbrook	Low trim	9	64	27	100
	Low leave	8	55	37	100
	High trim	18	48	34	100
	High leave	3	45	52	100
Princeton	Low trim	62	38	0	100
	Low leave	67	33	<1	100
	High trim	47	49	4	100
	High leave	52	46	2	100
Riske Creek	Low trim	47	44	9	100
	Low leave	60	38	2	100
	High trim	43	55	2	100
	High leave	35	47	18	100
Coastal					
Eve River	Low trim	23	23	54	100
	Low leave	14	22	64	100
	High trim	49	19	32	100
	High leave	41	10	49	100
Beaver Cove	Low trim	32	15	53	100
	Low leave	14	38	48	100
	High trim	35	39	26	100
	High leave	30	28	42	100

Again, live-limb height should increase with density and age; overall, the data support this trend. The more dense Eve River stand had a mean lowest live-limb height of 42.9 cm while the less dense Beaver Cove had an average of 37.2 cm. However, the Coastal treatment blocks did not follow this trend. The height distribution by treatment classes in Table 3 show that 50% of the stems at Eve River and 58% at Beaver Cove had limbs at or below 30 cm.

The Treatment

Before cutting at any of the locations, a backline was cleared to prevent cut stems from "hanging up" on the first pass. The operators worked across and up the slope. Fuelling and blade maintenance were performed as required while general saw maintenance was done on a daily basis.

Interior. Table 4 gives the post-treatment density levels. At the Cranbrook and Riske Creek sites, the overall average stems per hectare of 1505 and 1330 meet the prescribed densities of 1500 and 1300 stems/ha. At Princeton, the target of 1500 stems/ha was missed with only 1275 stems/ha remaining after treatment. Tree selection was difficult because the stand was clumpy and 15-20% of all stems had basal scars of unknown origin.

At two of the three sites, the sapling count exceeded that of the crop trees. For the purposes of the live-limb survival study, saplings were classified as all stems over 30 cm in height not designated as crop trees. In operational practice, only stems higher than 0.5 m and not designated as crop trees are counted as saplings.

The average stump heights measured after treatment are shown in Table 4. The target height of 10 cm or less for the lower cutting treatment was easily met at the Princeton and Riske Creek sites. However, as stand density and slash increased, so did the stump heights, as shown at the Cranbrook site. The high-cut target height of 30 cm was easily met where prescribed.

The post-treatment distribution of stumps with live limbs is illustrated in Table 5. In all locations, the trim treatments have approximately 50% fewer stumps with live limbs than the untrimmed blocks. This, to some degree, is a measure of the efficacy of trim treatments and also reflects the average height of the lowest live limb (Table 2).

Coastal. The crop-tree densities of 1050 and 900 stems/ha achieved at Eve River and Beaver Cove (Table 4) were close to the target densities of 1000 and 890 stems/ha.

Table 4. Stocking and Stump Heights: Post-Treatment Data

Location	Treatment	Crop trees (stems/ha)	Prescription (crop trees/ha)	Saplings >30 cm height (stems/ha)	Average stump height (cm)
Interior					
Cranbrook	Low trim	1 380	1 500	1 600	9.3
	Low leave	1 500		1 460	15.9
	High trim	1 700		2 240	30.8
	High leave	1 440		4 920	29.9
Overall		1 505		2 555	n/a
Princeton	Low trim	1 246	1 500	1 090	8.5
	Low leave	1 340		820	8.6
	High trim	1 240		660	28.6
	High leave	1 280		820	28.2
Overall		1 275		850	n/a
Riske Creek	Low trim	1 380	1 300	680	6.6
	Low leave	1 360		1 160	8.9
	High trim	1 380		840	33.8
	High leave	1 200		1 220	32.9
Overall		1 330		975	n/a
Coastal					
Eve River	Low trim	984	1 000	1 170	16.0
	Low leave	1 040		1 180	17.3
	High trim	1 260		1 440	30.9
	High leave	920		1 960	34.4
Overall		1 050		1 435	n/a
Beaver Cove	Low trim	980	890	680	19.5
	Low leave	920		2 800	18.4
	High trim	800		1 260	33.3
	High leave	900		1 400	32.0
Overall		900		1 535	n/a

Table 5. Stumps with Live Limbs After Each Treatment: Pine or Hemlock Only[a]

Location	Treatment	Pine or hemlock only (%)
Interior		
Cranbrook	Low trim	15
	Low leave	35
	High trim	35
	High leave	80
Princeton	Low trim	17
	Low leave	45
	High trim	56
	High leave	69
Riske Creek	Low trim	24
	Low leave	40
	High trim	56
	High leave	93
Coastal		
Eve River	Low trim	9
	Low leave	21
	High trim	40
	High leave	31
Beaver Cove	Low trim	18
	Low leave	36
	High trim	38
	High leave	46

[a] Based on 1987 plot counts of all stumps.

As in the Interior study sites, the sapling counts on the Coastal sites were high. These saplings, less rigid than the pine saplings in the Interior, were bent over and buried by the trees felled during thinning. Overall, the average stump height in the hemlock stands was higher than the average stump height in the pine stands. Increased slash and rougher terrain made it more difficult to cut low stumps on these sites than in the Interior.

At both Eve River and Beaver Cove, the low-trim treatments yielded 50% or fewer stumps with live limbs than did the low-leave treatments (Table 5). In both the high treatments at Beaver Cove, there was less difference between those stumps where branches had been trimmed and those stumps where branches had been left (38% versus 46%). Eve River followed a reverse trend (40% versus 31%), perhaps due to the higher incidence of live branches occurring at or below 30 cm before stand treatment (Table 3).

RESULTS

Stump Survival

Interior. Table 6 summarizes data for stump survival and shows that several general trends occurred over the two-year study period. Stumps with the lowest survival rate were those receiving a trim treatment. Specifically, the low-trim treatment had the lowest survival rate. The Cranbrook high-trim block was the only exception and the data suggest no conclusive reason for this. The overall highest survival was in the high-leave areas.

ANOVA testing showed that both main treatments, high cut versus low cut and trim versus leave, significantly affected stump survival, in both 1988 and 1989 (α[1] = 0.05). Stumps in the trim treatments had greater mortality than stumps in the leave treatments, and stumps in the low treatments had greater mortality than those in the high treatments. Analysis of the 1989 data suggested an interaction between high-cut versus low-cut and trim versus leave treatments. High cut versus low cut had a large effect on mortality when combined with the leave treatment, but not when combined with the trim treatment. Duncan's multiple range testing showed 1989 mortality in the high-leave treatment was significantly lower than for the other three treatment combinations; however, the mortality rates associated with the other three combinations were not significantly different from each other (α = 0.05).

Mortality occurred throughout the first two growing seasons after treatment. Appendix I summarizes data for surviving stumps only and shows general trends. Over the two-year study period the average stump height increased, average stump diameter decreased, and average number of live limbs per stump increased. This indicates that higher stumps with smaller diameter and more live limbs had a higher survival rate.

To test correlations between initial stump characteristics and survival rates, stumps for each treatment were sorted into high and low groups, with each pair based on stump diameter, stump height, number of live limbs per stump, distance to nearest competitor, and distance to nearest crop tree. Mortality was calculated for each. Analysis of variance testing showed that groups of stumps with larger diameters had significantly greater mortality than groups of stumps with smaller diameters, groups of low stumps had significantly greater mortality than groups of high stumps, and groups of stumps with fewer live limbs had significantly greater mortality than those groups with more live limbs (α = 0.05). There was no significant difference between groups based on distance to nearest competitor or nearest crop tree. The test results were similar in both 1988 and 1989.

Coastal. The Coastal hemlock stands had the fewest surviving stumps in the trim treatments (Table 6). Though the trends were similar to those seen with the Interior lodgepole pine, the actual survival percentages in the hemlock treatments were generally higher. Overall, the highest survival occurred with the high-leave treatment and the lowest survival in the low-trim treatment.

[1] α = size of Type I error; probability of rejecting a hypothesis when true. In this study, the null hypothesis in each case was "no effect due to treatment."

Table 6. Summary of Tagged Stumps: Stump Survival

Treatment type	Interior			Coastal	
	Cranbrook (% survival)	Princeton (% survival)	Riske Creek (% survival)	Eve River (% survival)	Beaver Cove (% survival)
Low trim	22	18	6	51	43
Low leave	33	28	24	64	44
High trim	10	31	18	52	54
High leave	48	81	73	80	62

ANOVA testing showed that both high-cut versus low-cut and trim versus leave treatments had a significant effect on stump survival in 1988 ($\alpha = 0.05$). When the 1989 data were examined, it was revealed that treatment had only borderline significance ($\alpha = 0.05$) which suggests that stump mortality was accelerated by the low-cut and trim treatments during the first year.

Appendix I summarizes data for surviving stumps only and shows the same survival traits seen in the Interior pine: i.e., higher stumps of smaller diameter with increasing live-limb density. Again the data were grouped based on initial stump characteristics, and differences in survival rates were tested. Because juvenile spacing on the Coastal sites took place in the spring of 1988, the first year's mortality rate was low; the ANOVA testing showed no significant effect on mortality in 1988 ($\alpha = 0.05$). However, testing of the 1989 data showed that groups of stumps with large diameters had significantly poorer survival than groups of stumps with smaller diameters, groups of low stumps had significantly poorer survival than groups of high stumps, and groups of stumps with fewer live limbs had significantly poorer survival than those groups with more live limbs ($\alpha = 0.05$).

Grouping stumps based on distance to nearest competitor or nearest crop tree showed no significant correlation ($\alpha = 0.05$) except in 1988. A borderline significant interaction between distance to closest crop tree and trim versus leave treatment was found. Survival was significantly lower in the group farther from a crop tree and this effect was more evident in the trim than in the leave treatments. This suggests that stumps closer to crop trees benefitted from some form of protection, especially in the trim treatments.

Characteristics of Limbs Growing on Surviving Stumps

Interior. Table 7 tracks and summarizes the characteristics of limb growth on 1989 surviving stumps. The live branches on the cut stumps increased in total length and foliated length in all treatments and at all locations except the low-leave treatment at Cranbrook.[2] The average foliated length per stump increased, proportionately, more than the average total length per stump in all treatments except the high-trim treatment at Cranbrook. This suggests that the branches were healthy and would continue to grow at least until crown closure by the crop trees. At all sites, except for Riske Creek's low-cut treatment area, the proportionate limb growth in the trim treatment was greater than that in the leave treatment. The Riske Creek exception may be explained by the large amount of new growth in the form of epicormic limbs (Table 8).

ANOVA testing showed that branch diameter, total length, green length, and number of branches per stump were significantly different for the trim versus leave treatment ($\alpha = 0.05$). In contrast, the number of branches per stump was significantly different when results for the high-cut versus low-cut treatment were compared ($\alpha = 0.05$). The total average branch diameter was significantly larger at Princeton than at Cranbrook or Riske Creek ($\alpha = 0.05$), otherwise there were no significant differences between the three sites.

In 1989, the height of the dominant limb on each surviving stump and the height of the nearest crop tree were both recorded (Table 9). Generally, the limb heights associated with the trim treatments were lower than those in the leave treatments, and limb heights in the high treatments were higher than those in the low. When the limb height is expressed as a percentage of the crop tree height, the percentages range from 7% to 24%.

Coastal. Table 7 summarizes the average limb-growth characteristics of the 1989 surviving stumps. Limb growth and development were similar for all treatments on both sites. ANOVA testing showed no significant treatment effect on any of the measured characteristics ($\alpha = 0.05$). However, high cut versus low cut was of borderline significance for the number of branches per stump; the low stumps had fewer limbs than the high stumps ($\alpha = 0.05$). In all treatments but one, the foliated length (green length) increased, proportionately, more than total lengths; this suggests the branches were healthy and vigorous. In the low treatments, the total growth per stump was much less in the trim treatment than in the leave treatment, while the reverse was true in the high treatments.

The trend in western hemlock was generally towards lower branch heights in the trim treatments and low treatments (Table 9). Average branch height, expressed

[2] Total length = sum of the total length of all live limbs including foliated and nonfoliated sections. Green or foliated length = sum of the foliated section of all live limbs on a particular stump.

Table 7. Live-Limb Length and Growth on Surviving Stumps, 1989

		Interior						Coastal			
		Cranbrook		Princeton		Riske Creek		Eve River		Beaver Cove	
Treatment	Year	Average green length/ stump (mm)	Average total length/ stump (mm)	Average green length/ stump (mm)	Average total length/ stump (mm)	Average green length/ stump (mm)	Average total length/ stump (mm)	Average green length/ stump (mm)	Average total length/ stump (mm)	Average green length/ stump (mm)	Average total length/ stump (mm)
Low trim	1987	146	225	379	555	227	357	767	1 308	1 974	2 554
	1988	201	267	463	584	340	400	1 058	1 380	2 417	2 951
	1989	278	355	635	865	377	463	1 348	1 647	2 700	3 138
% new growth		90	58	68	56	66	30	76	26	37	23
Low leave	1987	411	629	472	681	449	692	2 146	2 405	1 663	2 087
	1988	397	588	531	723	550	732	2 258	2 753	1 942	2 267
	1989	431	639	719	901	846	1 143	2 913	3 423	2 508	2 817
% new growth		5	2	52	32	88	65	36	42	51	35
High trim	1987	514	682	440	671	482	713	1 722	2 269	1 421	1 769
	1988	545	741	477	687	570	744	2 359	2 779	1 743	2 118
	1989	560	832	835	1 101	688	978	3 393	3 783	2 321	2 649
% new growth		9	22	90	64	43	37	97	67	63	50
High leave	1987	1 560	1 967	1 432	1 825	1 219	1 813	3 486	4 289	2 716	3 277
	1988	1 629	2 069	1 702	2 086	1 286	1 884	4 211	4 810	3 154	3 698
	1989	1 938	2 362	2 244	2 597	1 497	2 096	5 216	5 812	4 278	4 709
% new growth		24	20	57	42	23	16	50	36	58	44

Table 8. Occurrence and Survival of Epicormic Limbs

		1988				1989				1988-1989: Survivors			
Location	Treatment	No. stumps with	% of total stumps	No. epicormics	Avg/ stump	No. stumps with	% of total stumps	No. epicormics	Avg/ stump	No. stumps with	No. epicormics	Avg/ stump	% survival
Interior													
Cranbrook	Low trim	5	45	9	1.8	4	50	6	1.5	1	1	1.0	11
	Low leave	8	38	13	1.6	7	44	12	1.7	7	7	1.0	58
	High trim	3	27	10	3.3	0	0	0	0	2	4	2.0	40
	High leave	8	26	9	1.1	5	21	8	1.6	2	3	1.5	33
Riske Creek	Low trim	1	25	1	1.0	1	33	1	1.0	1	1	1.0	100
	Low leave	12	63	23	1.9	3	25	8	2.7	10	20	2.0	87
	High trim	10	50	25	2.5	3	33	7	2.3	6	9	1.5	36
	High leave	24	56	51	2.1	14	38	36	2.6	22	48	2.2	94
Princeton	Low trim	7	32	17	2.4	2	25	3	1.5	3	3	1.0	18
	Low leave	7	37	16	2.3	2	14	5	2.5	6	13	2.2	81
	High trim	16	67	55	3.4	6	40	27	4.5	10	23	2.3	42
	High leave	16	37	41	2.6	17	45	35	2.1	14	40	2.9	98
Coastal													
Eve River	Low trim	3	9	5	1.7	1	4	1	1.0	0	0	0	0
	Low leave	4	9	12	3.0	3	9	6	2.0	3	10	3.3	83
	High trim	6	15	17	2.8	3	23	5	1.7	5	15	3.0	88
	High leave	6	13	9	1.5	3	15	4	1.3	3	6	2.0	67
Beaver Cove	Low trim	5	13	7	1.4	2	15	2	1.0	2	2	1.0	29
	Low leave	6	14	10	1.7	2	9	2	1.0	4	6	1.5	60
	High trim	6	14	10	1.7	2	8	2	1.0	2	3	1.5	30
	High leave	5	10	7	1.4	1	3	1	1.0	4	6	1.5	86

Table 9. Average Heights of Dominant Limb Tips and Crop Trees, 1989

Location	Low trim			Low leave			High trim			High leave		
	Limb tip (cm)	%	Crop tree (cm)	Limb tip (cm)	%	Crop tree (cm)	Limb tip (cm)	%	Crop tree (cm)	Limb tip (cm)	%	Crop tree (cm)
Interior												
Cranbrook	28	7	389	44	13	340	38	12	327	72	23	314
Princeton	49	20	250	47	18	264	46	16	293	66	23	285
Riske Creek	23	9	267	30	16	183	34	14	246	68	24	280
Coastal												
Eve River	87	18	475	108	20	548	124	22	572	134	23	595
Beaver Cove	91	16	584	104	19	558	98	15	645	111	17	663

as a percentage of average crop-tree height, ranged from 16 to 23%.

Occurrence and Survival of Epicormic Limbs

During measurements carried out in 1988 and 1989, epicormic branches were counted. Epicormic branches, or shoots, are produced from dormant buds on the main stem or branches of trees which are stimulated by sudden exposure to light. Those epicormics recorded in 1988 that survived through to 1989 were measured and added to the individual stump's growth record. Table 8 outlines the occurrence and survival of these branches.

Interior. Epicormic branching occurred on 25-67% of all tagged live lodgepole pine stumps by 1988. This decreased to 0-50% by 1989, based on the number of live stumps surviving that year. Generally, the trim treatments in 1988 had fewer stumps with epicormic branches, but these stumps had more per stump than the other treatments. The Riske Creek low-trim treatment area was the exception, but it also had the greatest stump-mortality rate. In 1989 the leave treatments generally had more epicormic branches per live stump than the trim treatments; however, the Princeton high-trim treatment had the greatest number of all locations and treatments at 4.5 new branches per stump.

The survival rate of the 1988 epicormic branches into 1989 varied. Cranbrook had the lowest survival rate, followed by Princeton and then Riske Creek. Stumps earlier classified as dead did not regenerate with epicormic growth.

Coastal. The incidence of epicormic branching on the Coastal hemlock sites was less than on the Interior pine areas. By the autumn of 1988, 9% to 15% of all tagged stumps had sprouted epicormic limbs. By 1989, 3% to 23% of all surviving stumps had epicormic limbs. Overall, fewer epicormic limbs were produced between 1988 and 1989.

Overall, the survival of the 1988 epicormics into 1989 was 50% or better. One stump, in the low-leave treatment at Eve River, was recorded as "dead" in the fall of 1988; however, it sprouted two epicormic branches from the stump and two epicormic shoots on previously dead branches. But, this was not a common occurrence.

Productivity

The figures in Table 10 have been adjusted to reflect the cutting time (i.e. cutting and moving time only) per hectare by location and treatment type.

Interior. The cutting time per hectare was generally related to stand density and difficulty of treatment. Princeton, with the fewest trees per hectare, was cut the fastest, followed by Riske Creek and Cranbrook, both of which had higher initial densities. At Cranbrook, the low-leave treatment took slightly longer to carry out than the low-trim treatment when only cutting time is considered. The reason is that this was the first block the operator treated. However, 11.7 h/ha for the low-trim block in Princeton is higher than expected. The very stony soil, with little or no duff layer, possibly increased blade wear, especially when removing the live limbs from the stumps. Though the blade was filed whenever the saw was refuelled, it could have been used in a dull condition for some time between fuel stops. The low initial stocking of the block (9700 trees/ha), plus the basal scarring mentioned earlier, could have made the crop-tree selection process more time consuming.

Coastal. The data from the two Coastal sites are difficult to compare because the two operators involved had different levels of experience. The generally higher initial densities plus increased slash loading in the block at Eve River slowed production considerably compared to the Interior stands. Tight basal branching on the young hemlock trees in this block made it difficult to approach the boles with a clearing saw. The longer branches interlocked and this increased hang-ups and impeded visibility. The effect of these two drawbacks can be seen by comparing the high-leave blocks at Cranbrook to those at Eve River. The former had an initial stocking of 45 700 trees/ha and took 18.6 h/ha to cut, whereas the latter had a lower initial stocking of 33 500 trees/ha and took 33.9 h/ha to cut (Table 10). Table 11 illustrates this even more clearly; 35.2 trees/

Table 10. Cutting Time per Hectare,[a] by Location and Treatment Type

Treatment type	Interior			Coastal	
	Cranbrook (h)	Princeton (h)	Riske Creek (h)	Eve River (h)	Beaver Cove (h)
Low trim	23.4	11.7	10.0	38.4	52.1
Low leave	28.1	5.7	6.0	33.8	41.8
High trim	35.5	18.5	21.3	41.0	47.6
High leave	18.6	5.4	6.0	33.9	45.5

[a] *Cutting and moving time only* for the 0.25-ha blocks has been converted to give total *cutting and moving time only* for one hectare.

Table 11. Productivity: Stems/min by Location and Treatment Type

Treatment type	Interior			Coastal	
	Cranbrook	Princeton	Riske Creek	Eve River	Beaver Cove
Low trim	15.3	10.5	28.2	21.4	13.7
Low leave	12.8	26.2	38.0	25.5	16.4
High trim	12.0	9.2	18.5	16.0	9.2
High leave	35.2	32.8	39.8	15.1	9.3

min were cut in Cranbrook versus 15.1 trees/min in Eve River. The Beaver Cove data, when compared to Eve River, illustrate the difference between an inexperienced operator, at 45.5 h/ha, and one with several weeks of experience, at 33.9 h/ha.

Costs

The hourly operating costs for the Husqvarna 165RX clearing saw listed in Appendix II, including the operator, were calculated using the standard FERIC costing formula.

Table 12 gives the costs per hectare by location and treatment type. Assuming that the most desirable treatment from a biological viewpoint would be low trim, the costs range from $235/ha to $545/ha in the Interior pine stands, and from $895/ha to $1215/ha in the Coastal hemlock stands.

DISCUSSION

Promnitz and Lin (1985)[3] examined the seven-year growth of spaced conifer stands at different levels of competition from residual understorey trees on Vancouver and Moresby Islands. The impact of less-than-complete competition removal was most significant for western hemlock and poor site Douglas-fir. Different levels of understory tree competition had little effect on crop-tree growth for Sitka spruce and Douglas-fir on better sites.

Gay (1987)[4] measured the live-limb survival and growth response in a nine-year-old lodgepole pine stand near Cranbrook, B.C. which had undergone juvenile spacing. He found that survival of stumps with live limbs averaged 36% (after four years), with most mortality occurring in the first two years. Primary growth performance of the crop trees was 2.5 times greater than that exhibited by the stumps with live limbs. Regression analysis showed no relation between the survival of these limbs and either stump height or stand density.

The results of the FERIC study showed significant differences among the four treatments. The trim treatments left 50% fewer stumps with live limbs, and ANOVA testing showed both trim versus leave and high-cut versus low-cut treatments significantly affected subsequent survival of stumps with live limbs (α = 0.05).

As expected, the low-trim treatments had the lowest stump survival, and the high-leave treatments had the highest. Also, ANOVA testing showed both main treatments, high cut versus low cut and trim versus leave, had a significant effect on survival rate in both years for lodgepole pine and western hemlock.

Cutting low had a greater effect on survival in the leave treatment than in the trim treatment, as suggested by ANOVA testing. This suggests that trimming was the main contributor to mortality. Cutting low significantly reduced the number of live limbs per stump for both species. This may explain the difference in survival.

[3] L.C. Promnitz and J.Y. Lin, 1985; "Competition of understory trees in a juvenile spaced stand"; Crown Forest Products, Project No. 2-009, unpublished report, 10 pp.

[4] R.C. Gay, 1987; "Live branch survival and growth response in juvenile-spaced lodgepole pine in the Nor fire (BCMOF SX Trial No. 82408)"; unpublished report submitted to the Assoc. of B.C. Professional Foresters.

Table 12. Cost by Location and Treatment Type [a]

Treatment type	Interior			Coastal	
	Cranbrook ($/ha)	Princeton ($/ha)	Riske Creek ($/ha)	Eve River ($/ha)	Beaver Cove ($/ha)
Low trim	545	275	235	895	1 215
Low leave	655	135	140	785	975
High trim	830	430	495	955	1 110
High leave	435	125	140	790	1 060

[a] Total equipment cost excluding interest.

ANOVA testing of survival between stumps grouped by initial stump diameter, stump height, and number of live limbs per stump showed significant correlations. Stumps in groups with the smaller stump diameter, greater stump height, and more live limbs per stump had significantly higher average survival rates than those in groups with larger diameter, lower stump height, and fewer live limbs per stump.

ANOVA testing of the lodgepole pine stump-growth characteristics showed that limb diameter, total length, green length, and number of limbs per stump were significantly different for the trim versus leave treatment among 1989 survivors. This suggests that stumps in the leave treatments are more vigorous than stumps in the trim treatments. Only the number of limbs per stump was significantly different for the high-cut versus low-cut treatment. This would help to explain the greater influence of the trim treatments on survival. Whether significant differences in stump-growth characteristics indicate significant differences in the stumps' competitive ability towards the crop trees is unknown.

ANOVA testing of stump-growth characteristics for the 1989 survivors showed no significant differences among the four treatments in Coastal western hemlock. This may be a result of the characteristic shade tolerance of this species. There were significantly fewer limbs per stump associated with the low treatment than with the high treatment, as was expected. Despite this, the overall data indicate that living stumps, no matter what the treatment, would provide similar levels of competition for the crop trees. Therefore, the levels of competition posed to the remaining crop trees will be proportional to the differences in survival among the four treatments.

This study did not address whether or not the differences in numbers of stumps with live limbs for the various treatments will significantly affect the growth of the remaining crop trees. Gay (1987) predicted that of all the stumps with live limbs in his study of lodgepole pine, only 25% may live to rotation age and form part of the stand. A much larger percentage of stumps would be expected to survive to rotation for the more shade-tolerant western hemlock.

CONCLUSIONS

Four methods of stem treatment were carried out during juvenile spacing in three Interior lodgepole pine stands and two Coastal western hemlock stands in British Columbia. Stems were cut as low as possible or at a height of 30 cm, and remaining live limbs were trimmed or left untouched.

Of the two main treatments, the trim versus leave treatment had the greatest effect on stump survival. Trimming had two effects; the number of stumps with live limbs remaining were 50% fewer than with the leave treatments, and survival was poor on trim treatments. Stumps with smaller initial diameters, greater heights, and more live limbs had the highest survival as a group. Of the four treatment combinations, the high-leave treatment had the highest survival, whereas the other three treatment combinations had lower rates of survival which were not significantly different from each other. Though extra effort is required and costs are higher for the trim treatment, these need only be expended if cutting low is not a feasible treatment option; otherwise, low leave may be the most cost effective and operationally acceptable treatment method.

The implications for mechanical strip thinning are the same. If cutting low is not a feasible treatment, some other mechanism will be needed to address trimming low live limbs on high stumps.

Epicormic branching in general did not seem to be important. It was generally confined to stumps which already had live branches, and should, therefore, be looked at only as an impediment to the growth of the more dominant branches.

Further research is required to determine whether or not the decrease in stump survival associated with the low and trim treatments is biologically and economically justifiable. The long-term impact of stump survival on crop-tree growth needs to be quantified.

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APPENDIX I

Data Summary: Surviving Stumps in 1989 (Including Old Epicormics)

Interior

Location	Treatment	Year	No. of surviving stumps [a]	Avg stump diam. (mm)	Avg stump height (mm)	Total no. of live limbs [b]	Avg branch diam. (mm)	Avg no. branches/ stump	Avg branch height [c] (mm)	Avg total length [d] (mm)	Avg green length [e] (mm)	Avg dist. to nearest competitor (mm)	Avg dist. to nearest crop tree (mm)
Cranbrook	Low trim	1987	37	25	115	48	3	1.3	91	212	105	356	976
		1988	11	17	134	18	4	1.6	107	161	111	441	788
		1989	8	14	146	20	6	2.5	108	142	111	461	745
	Low leave	1987	47	25	190	102	4	2.2	166	252	147	346	871
		1988	21	16	232	57	4	2.6	194	198	133	373	870
		1989	16	16	252	48	6	3.0	205	213	144	379	838
	High trim	1987	50	29	331	93	4	1.9	201	246	155	397	832
		1988	11	21	357	27	4	2.4	197	249	164	213	795
		1989	5	17	258	19	6	3.8	167	219	147	188	904
	High leave	1987	50	27	332	228	4	4.6	211	322	237	257	1 044
		1988	32	26	342	174	7	5.6	226	344	269	297	1 108
		1989	24	26	339	146	9	6.1	227	388	319	303	1 045
Princeton	Low trim	1987	45	30	94	79	4	1.8	52	252	154	396	830
		1988	21	25	107	38	5	1.8	55	271	193	364	822
		1989	8	24	100	21	10	2.6	43	330	242	456	739
	Low leave	1987	50	30	98	99	5	2.0	57	319	196	423	883
		1988	19	28	115	37	7	2.0	56	378	276	415	665
		1989	14	24	113	40	11	2.9	57	316	252	535	889
	High trim	1987	48	28	287	110	4	2.3	110	237	139	349	869
		1988	21	22	277	51	5	2.4	90	260	180	387	985
		1989	15	20	271	75	8	5.0	103	220	167	539	997
	High leave	1987	47	24	280	266	5	5.7	177	286	220	290	979
		1988	43	23	280	259	6	6.0	172	319	258	307	991
		1989	38	23	283	290	10	7.6	166	340	294	297	978
Riske Creek	Low trim	1987	50	26	72	73	3	1.5	38	237	117	460	978
		1988	4	14	88	7	4	2.0	37	235	209	1 088	1 088
		1989	3	13	80	8	6	2.7	40	174	141	1 197	1 197
	Low leave	1987	50	22	101	99	4	2.0	55	216	121	487	997
		1988	19	22	102	47	5	2.5	50	248	178	576	989
		1989	12	18	105	63	7	5.2	48	218	161	682	915
	High trim	1987	50	23	332	124	4	2.5	137	233	136	402	1 098
		1988	20	16	310	54	4	2.7	114	218	164	452	1 151
		1989	9	11	300	43	6	4.8	96	210	149	443	1 314
	High leave	1987	51	26	336	286	5	5.6	203	303	203	437	1 011
		1988	43	25	339	251	6	5.8	193	308	212	497	936
		1989	38	21	341	274	8	7.4	180	299	211	537	976

[a] Number of stumps with one or more live limbs.
[b] Total number of limbs for the whole treatment block.
[c] Limb height = Vertical distance of highest limb from the ground.
[d] Total length = Total branch length of live limbs on stump (including foliated and nonfoliated portions).
[e] Green length = Sum of length of foliated portion of all live limbs on stump.

Coastal

Location	Treatment	Year	No. of surviving stumps [a]	Avg stump diam. (mm)	Avg stump height (mm)	Total no. of live limbs [b]	Avg branch diam. (mm)	Avg no. branches/ stump	Avg branch height [c] (mm)	Avg total length [d] (mm)	Avg green length [e] (mm)	Avg dist. to nearest competitor (mm)	Avg dist. to nearest crop tree (mm)
Eve River	Low trim	1987	47	27	209	82	5	1.7	155	614	370	378	1 166
		1988	30	26	228	59	6	1.8	153	662	496	338	1 095
		1989	24	21	226	54	10	2.2	155	732	599	258	1 120
	Low leave	1987	50	36	233	138	5	2.8	153	742	498	369	991
		1988	43	39	231	118	9	2.8	159	852	682	535	1 085
		1989	32	31	242	120	13	3.8	160	913	777	482	894
	High trim	1987	50	30	320	154	5	3.1	184	571	400	330	1 055
		1988	40	30	328	136	7	3.4	194	663	525	360	987
		1989	26	24	351	142	10	5.5	199	693	621	326	1 010
	High leave	1987	50	31	351	349	5	7.0	198	492	400	213	1 097
		1988	46	32	357	318	7	7.2	199	604	525	204	1 087
		1989	40	33	351	315	10	7.9	196	738	662	310	1 140
Beaver Cove	Low trim	1987	49	35	233	107	6	2.2	179	751	537	443	1 166
		1988	40	34	235	91	7	2.3	149	828	637	435	1 050
		1989	20	28	273	68	13	3.4	138	923	794	514	1 236
	Low leave	1987	50	43	221	148	4	3.0	157	476	375	312	1 246
		1988	42	29	231	121	6	2.9	157	540	437	283	1 260
		1989	22	24	270	93	11	4.2	169	666	593	425	1 198
	High trim	1987	48	29	353	128	4	2.7	220	513	395	394	1 418
		1988	42	28	341	118	7	2.8	204	596	477	371	1 348
		1989	27	25	357	101	11	3.9	216	708	621	388	1 335
	High leave	1987	49	38	340	205	5	4.2	206	663	528	356	1 275
		1988	48	39	339	201	9	4.2	202	733	586	345	1 299
		1989	31	32	362	172	13	5.6	212	849	771	306	1 285

[a] Number of stumps with one or more live limbs.
[b] Total number of limbs for the whole treatment block.
[c] Limb height = Vertical distance of highest limb from the ground.
[d] Total length = Total limb length of live limbs on stump (including foliated and nonfoliated portions).
[e] Green length = Sum of length of foliated portion of all live limbs on stump.

APPENDIX II

Cost Analysis: Husqvarna 165RX Clearing Saw

Ownership costs: Input	
Purchase price (P)	$900
Salvage value (S), (20% of P)	$180
Expected life (yr)	1
Expected life (h)	1 500
Interest rate (I), (%)	11
Insurance (ins), (%)	3
Ownership costs: Results	
Average investment (AVI) = (P + S)/2	$540.00
Loss in resale value = (P - S)/h	$0.48/h
Interest = (Int • AVI)/(h/yr)	$0.03/h
Insurance = (Ins • AVI)/(h/yr)	$0.01/h
Operating and repair costs: Input	
Hourly fuel consumption (L/h)	1.0
Fuel cost ($/L)	$0.75
Annual operating cost (O)	$200
Annual repair and maintenance cost (R)	$250
Wages (W), ($/h)	$16.11 [a]
Wage benefit loading (WBL), (%)	35
Operating and repair costs: Results	
Hourly fuel cost = (L) • ($/L)	$0.75/h
Operating cost = O/(h/yr)	$0.13/h
Repair & maintenance cost = R/(h/yr)	$0.17/h
Labour cost = (W) • [1 + (WBL/100)]	$21.75/h
Total operating and repair costs	$22.80/h
Total costs: Results	
Loss in resale value	$0.48/h
Insurance	$0.01/h
Operating and repair costs	$22.80/h
Total equipment cost (excluding interest)	$23.29/h
Total equipment cost (including interest)	$23.32/h

[a] Forestry Crewman I rate.